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Technical Report

R 446

MULTIPURPOSE TYPE I (MP-1) FUEL FOR ANTARCTIC USE

May 1966

BUREAU OF YARDS AND DOCKS

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

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MULTIPURPOSE TYPE I (MP-1) FUEL FOR ANTARCTIC USE

Technical Report R-446

Y-F015-11-01-196

by

William W. W tson

ABSTRACT

The specifications for a multipurpose fuel, MP-1 (MIL-F-23188) have been developed by the Bureau of Naval Weapons. This fuel, proposed for use in Antarctica in aircraft turbines, diesel engines, and space heaters, has received prior approval for use in C-130 and C-135 aircraft. The current study was undertaken to determine its suitability for use in diesel engines, space heaters, emergency camp stoves, and lanterns.

These tests have indicated that MP-1 is a satisfactory substitute for DF-A (diesel fuel, arctic) in medium and high speed diesel engines, and in pot-type space heaters. MP-1 is not recommended as a regular fuel for pressurized, commercial camp stoves and lanterns which normally burn white gasoline, although under urgent conditions, it may be used in these units for short periods of time.

CONTENTS

INTRODUCTION

It is estimated that the Antarctic Forces consume approximately 5 million gallons of fuel annually, of which 40% is for heating purposes and 60% is for power generation and aircraft. As a result of the low temperatures prevailing in Antarctica, the primary requirement in these fuels is a very low pour point, with flow at -70°F being considered most desirable.

To provide a more effective fuel support for antarctic operations, a fuel simplification program was initiated by the Bureau of Naval Weapons about 3 years ago with the goal of developing a single fuel which would be compatible with jet turbines, compression-ignition engines and space heaters.

The result of this effort was the development of Specification MIL-F-23188 (28 February 1962): Fuel, Multipurpose, Antarctic; MP-1. (See Appendix A.) This was to be a fuel of limited availability, designed specifically to satisfy the requirements for extreme low-temperature operation in aircraft turbine engines, medium- and high-speed diesel engines, and space heaters. It was intended primarily for use in the Antarctic Deep Freeze Program, and was expected to replace both the currently used diesel fuel, arctic (DF-A) and JP-4 aviation turbine fuel in these areas.

MP-1 has previously been tested and approved for use in C-130 and C-135 aircraft.* This current report, covering the test and evaluation of MP-1 in diesel engines, space heaters, emergency camp stoves, and lanterns, is provided in response to requirements of the Bureau of Yards and Docks** and the Commander, Naval Support Force.***

PROCEDURES AND RESULTS

On 17 September 1964, an order was placed with the Baton Rouge Division of the Humble Oil & Refining Corporation for the refining and delivery of 6,425 gallons of a special fuel which would meet the specifications for MP-1 as outlined in Appendix A. This fuel, which has a limited availability and can be refined from a very restricted group of crude oils only, was delivered to the Naval Civil Engineering Laboratory (NCEL) about a month later. The specifications of the fuel as received

*Middletown Air Material Area message 202025Z of May 1964.
**BuDocks letter 42.310/fk:mvs of 5 Aug. 1964 to NCEL.
***COMNAVSUPPFOR letter serial W-449 of 9 July 1964 to BuDocks.

are reported in Appendix B. Two-thousand gallons of the MP-1 were immediately drummed and shipped to Antarctica for use in a preliminary evaluation of space heaters in service during the Deep Freeze 65 Program.

Diesel Engine Tests

The evaluation of MP-1 as a fuel for compression-ignition engines was performed in three stages, as follows:

1. A 500-hour endurance run conducted under load at ambient temperatures to determine combustion characteristics and the initial compatibility of MP-1 with fuel-injection systems (Reference 1).
2. A series of dynamometer tests to ascertain the magnitude of any power losses which might occur when MP-1 is substituted for DF-A, the current cold-weather diesel fuel.
3. Specialized laboratory tests of the fuel to determine its cold-flow and cold-ignition properties and thus indicate the cold-start and warmup performance level to be expected at very low temperatures.

Endurance Test. This phase of the task consisted of operating a matched pair of diesel engines under load for 500 hours. One engine ran on DF-A, while the other engine burned MP-1. (See Appendix C for a complete comparison of fuel characteristics.)

The two Caterpillar 50-kw diesel-electric generating sets (units nos. 51-01889 and 51-01890) selected for this test as being representative of equipment commonly employed in antarctic operations were in "like-new" condition when removed from storage (Figure 1). (See Appendix D for engine specifications.) To provide a standard basis for comparison, before the tests started all injection equipment (pumps and injectors) was removed from the engines, carefully inspected, tested, calibrated to the manufacturer's specifications, and reinstalled.

The test operation commenced on 12 January 1965 and continued 8 hours per day, 5 days per week for the complete 500-hour period. Power output of each unit was set at 44 kw, or 88% of full load, and was dissipated as heat to the atmosphere by means of a series of cal-rod strip heaters. Average fuel consumption during the test was 4.25 gallons per hour (0.63 lb fuel/kwh) for unit no. 51-01890 burning MP-1, and 4.05 gallons per hour (0.64 lb fuel/kwh) for unit no. 51-01889 burning DF-A.

Upon completion of the 500 hours of operation, the engines were disassembled for a detailed inspection of pistons, rings, valves, fuel injection pumps, and injectors. Injection pump delivery rates were checked with both fuels for comparison with original delivery rates. This posttest inspection found all parts from both engines in excellent condition, and no significant difference between the two could be detected. (See Figures 2, 3, 4, and 5.)

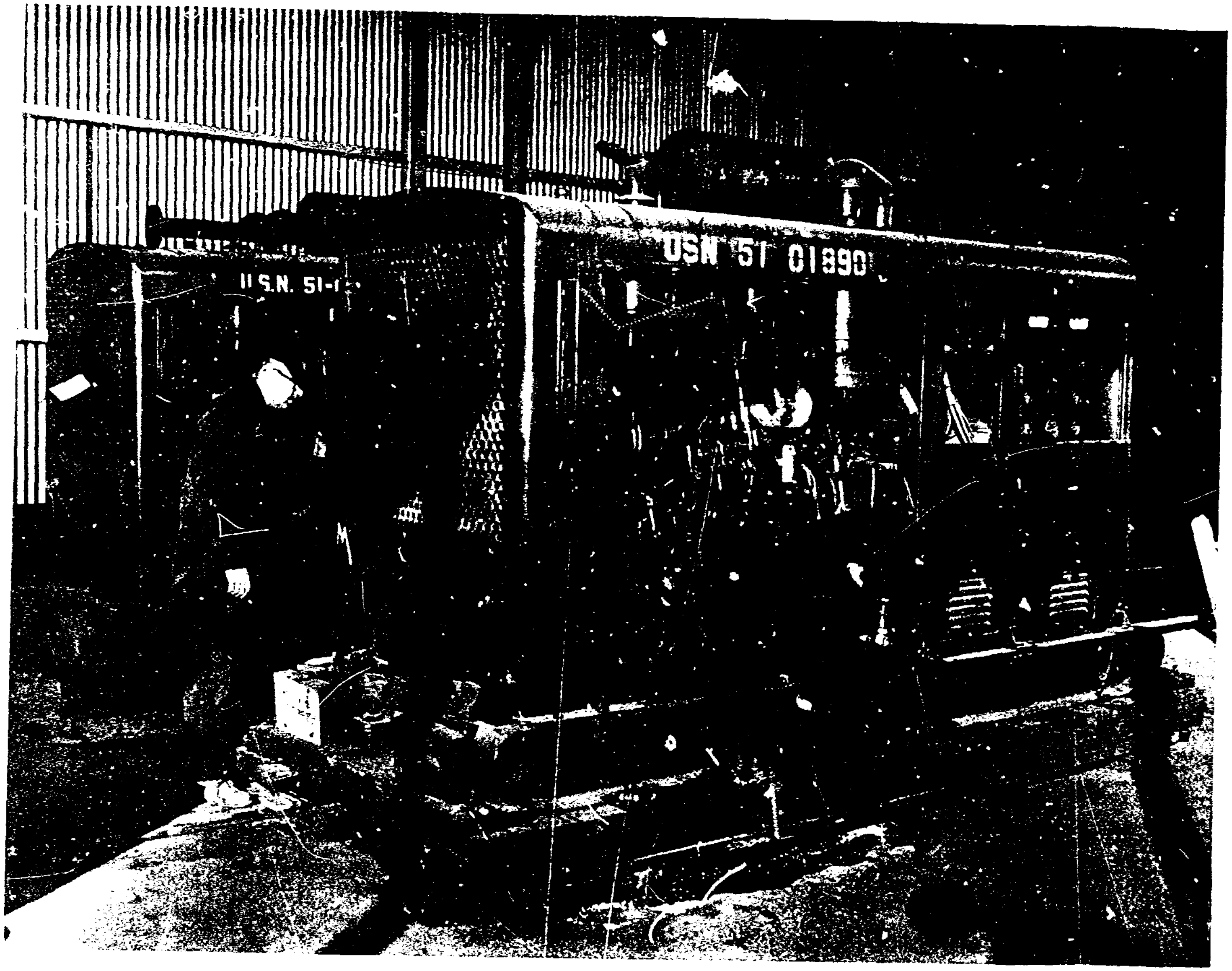

Figure 1. Caterpillar 50-kw diesel-electric generating set.

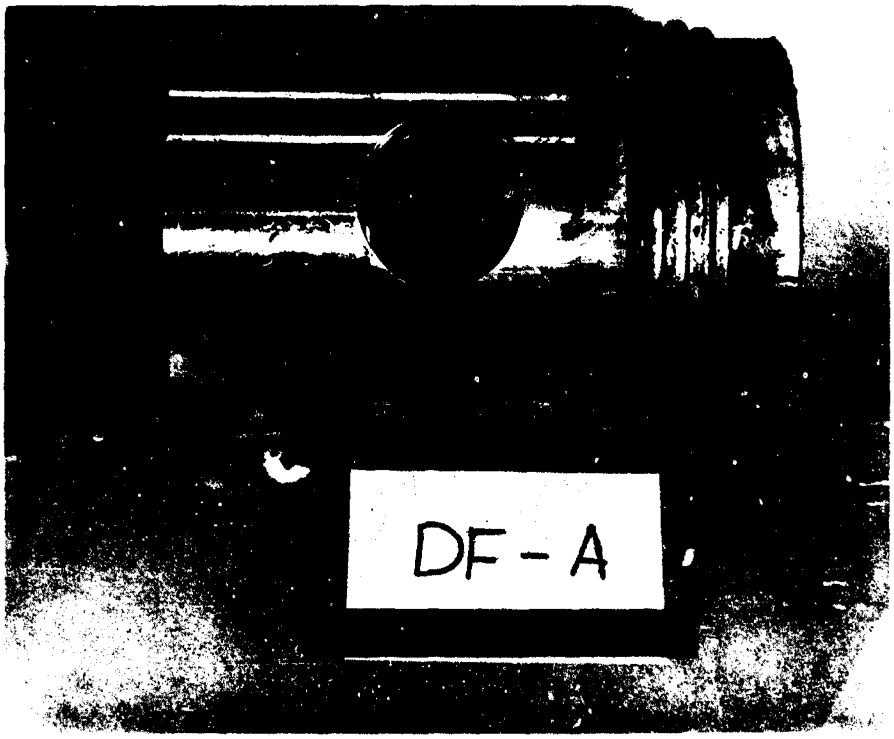

Figure 2. Piston and rings after 500 hours of operation on DF-A.

Figure 3. Piston and rings after 500 hours of operation on MP-1.

Figure 4. View of cylinder head showing combustion chambers, valves, and valve seats after 500 hours of operation on DF-A.

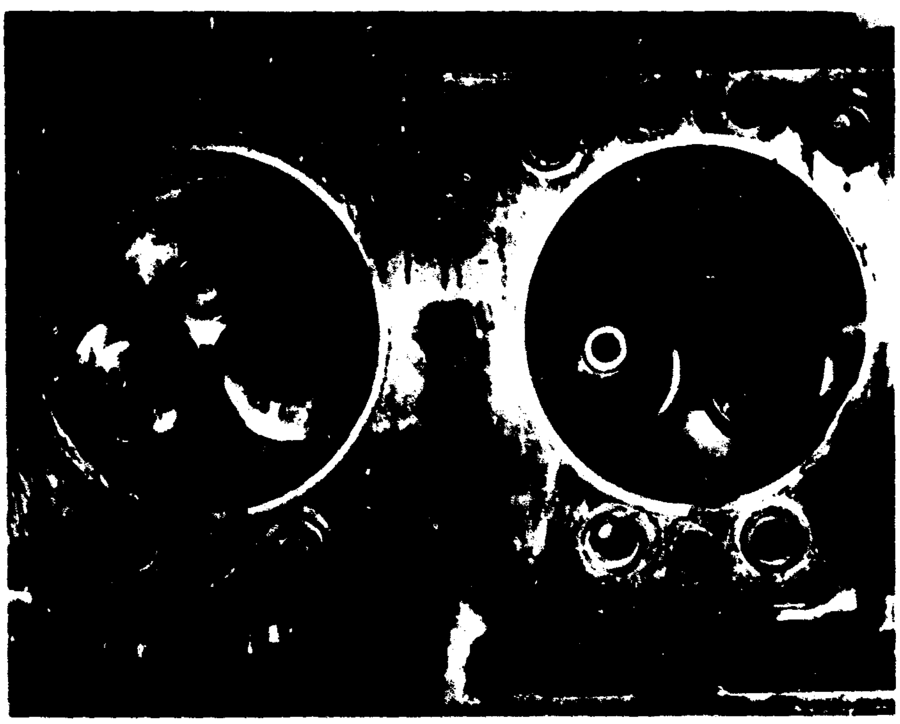

Figure 5. View of cylinder head showing combustion chambers, valves, and valve seats after 500 hours of operation on MP-1.

Of particular importance was the fact that the delivery rates of the two fuel-injection pumps were still well within the manufacturer's recommended limits after the 500 hours of operation. (See Appendix E for complete calibration results.) When disassembled, all injection pump plungers and barrels were in excellent condition, and it was concluded that the life of injection pumps of engines burning MP-1 should be most satisfactory.

An inspection and test of injectors following the 500-hour test disclosed that none of them leaked and that all of them opened at approximately 1,750 psi, as per manufacturer's specifications. However, the spray pattern of all four injectors which had operated on MP-1 did not appear to be normal, and in addition, the spray pattern of two of the injectors which had operated on DF-A appeared abnormal. To obtain additional expert opinion on this matter, these injectors were forwarded to the Research Department of the Caterpillar Tractor Company for a complete examination and analysis. Following this examination, the manufacturer reported* that: (1) the deviations noted in the spray patterns were normal for this type of valve, (2) one of the valves used with MP-1 did contain a manufacturing flaw, and (3) no problems were disclosed which could be related in any way to the use of one fuel versus the other.

Dynamometer Tests. To gain a better indication of the amount of power loss which might be expected from the use of a low-viscosity, low-specific-gravity fuel such as MP-1, arrangements were made to run a series of tests on a typical diesel engine with the new Clayton dynamometer installation at the Construction Battalion Center, Port Hueneme, California. The specific engine available for this test was a Hercules model DIX-6-D, which had just been completely overhauled and run-in. (See Appendix F for detailed specifications.)

To provide a standard for comparison, the first runs were made on DF-2 — the regular diesel fuel used at shore installations. A change was then made to DF-A, and finally to MP-1. All runs were made at 2,400 rpm, with the injection timing set as specified for the standard DF-2 fuel and the engine water-jacket temperature controlled at 175°F. Ambient temperature during the test period was approximately 68°F.

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*Caterpillar Tractor Company letter dated 15 September 1965 from D. C. Henderer to W. W. Watson of NCEL.

Results of this experiment were as follows:

Fuel	Maximum Horsepower Output	Brake Specific Fuel Consumption (lb/hp-hr)	Comments
DF-2 (standard)	71.5	0.64	Considerable black smoke at full throttle. Idles smoothly.
DF-A	68.5	0.61	Light black smoke at full throttle. Rough at high idle.
MP-1	68.5	0.57	No visible smoke at full throttle. Rough at high idle.

The loss of 3.0 horsepower (4.2%) for the change from DF-2 to either one of the two lighter fuels is considered a very nominal reduction. When calculated on the basis of reduced specific gravity and viscosity, a reduction of as much as 6.5% could be expected. As may be noted above, with this particular engine there was no power loss associated with the change from DF-A to MP-1.

Cold-Flow Tests. Field tests over the years have demonstrated that the most important single property of a diesel fuel used under extreme, low-temperature conditions is its ability to flow from the fuel tank to the engine. All diesel fuels will, of course, solidify and cease to flow at some definite temperature, with most of the readily available fuels reaching this condition within the range of 0 to -30°F. This solidification is due primarily to the formation of wax particles in the fuel. As the temperature decreases, the amount of wax that precipitates increases, and eventually the fuel sets up. Although the actual percentage of wax in the fuel is very small (ranging from 1% to 8%) its effect on engine operation can be catastrophic.

The traditional method for gaging the fluidity of a diesel fuel has been an inspection of its cloud and pour points as specified by ASTM (American Society for Testing Materials). Unfortunately, it has been found possible to have two fuels with very similar cloud and pour points and yet with very different flow properties. To discount the possibility that the cloud and pour points of MP-1 were not indicative of its flow characteristics, arrangements were made with the Enjay Laboratories Division of ESSO Research and Engineering in Linden, New Jersey, for them to conduct a series of flow tests (Reference 2). These tests measure the fluidity of a fuel at a number of temperatures, starting slightly above the ASTM cloud point and ranging down to below the ASTM pour point.

The test procedure consists of accurately measuring 3,400 to 3,800 ml of fuel into a 1-gallon can and storing it in a cold box at the desired temperature for 24 hours. A standard copper tube having a 3/16-inch OD is then inserted into the sample to approximately 1/8 inch from the bottom. After thermal equilibrium has been reached, a vacuum of 12 inches of mercury is applied to the system. The fuel is discharged outside of the cold box into a graduated cylinder, and the volume of fuel is recorded each minute until the fuel flow stops. (See Figure 6 for equipment setup.) The percentage of fuel removed from the container is then calculated. The test is repeated at progressively lower temperatures, and finally a plot of percentages of fuel removed against temperature is made.

Typical samples of four different fuels (DF-2, DF-A, JP-5, and MP-1) were forwarded to Enjay Laboratories to be subjected to the flow test. Results of these tests are shown graphically in Figure 7. The DF-2 and JP-5 samples were included in this test group to obtain comparative data on the behavior of warm weather (heavier) fuels at low temperatures.

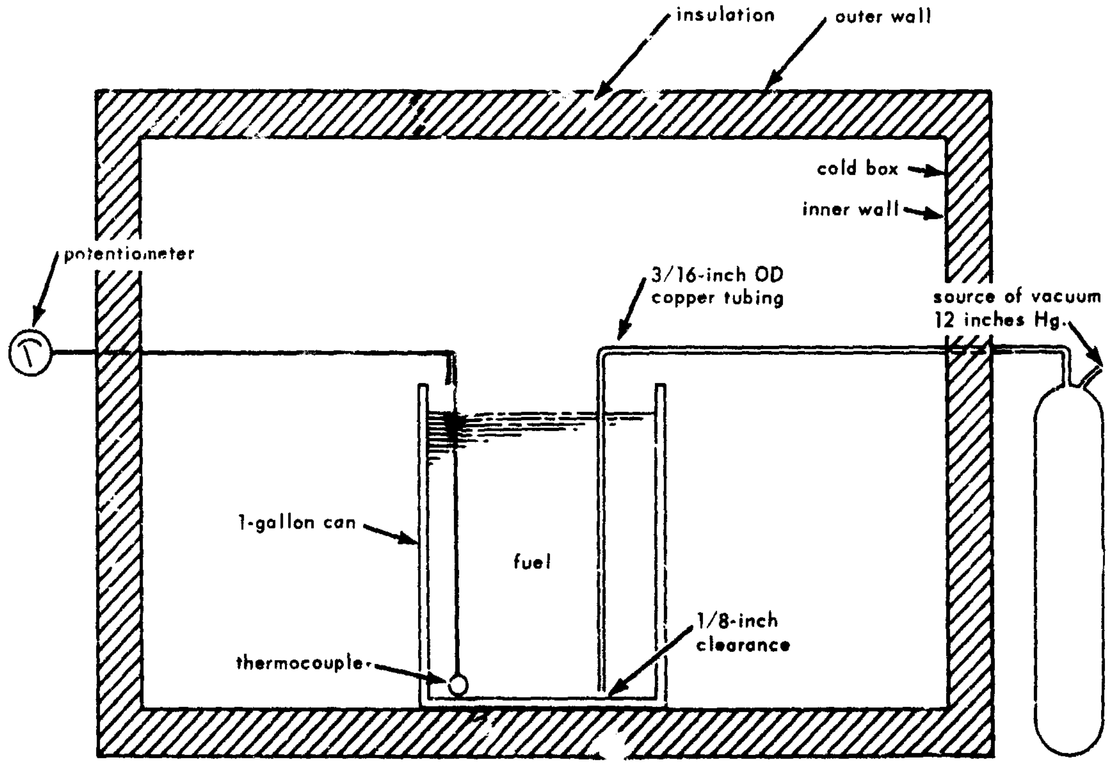

Figure 6. Cold-flow test apparatus.

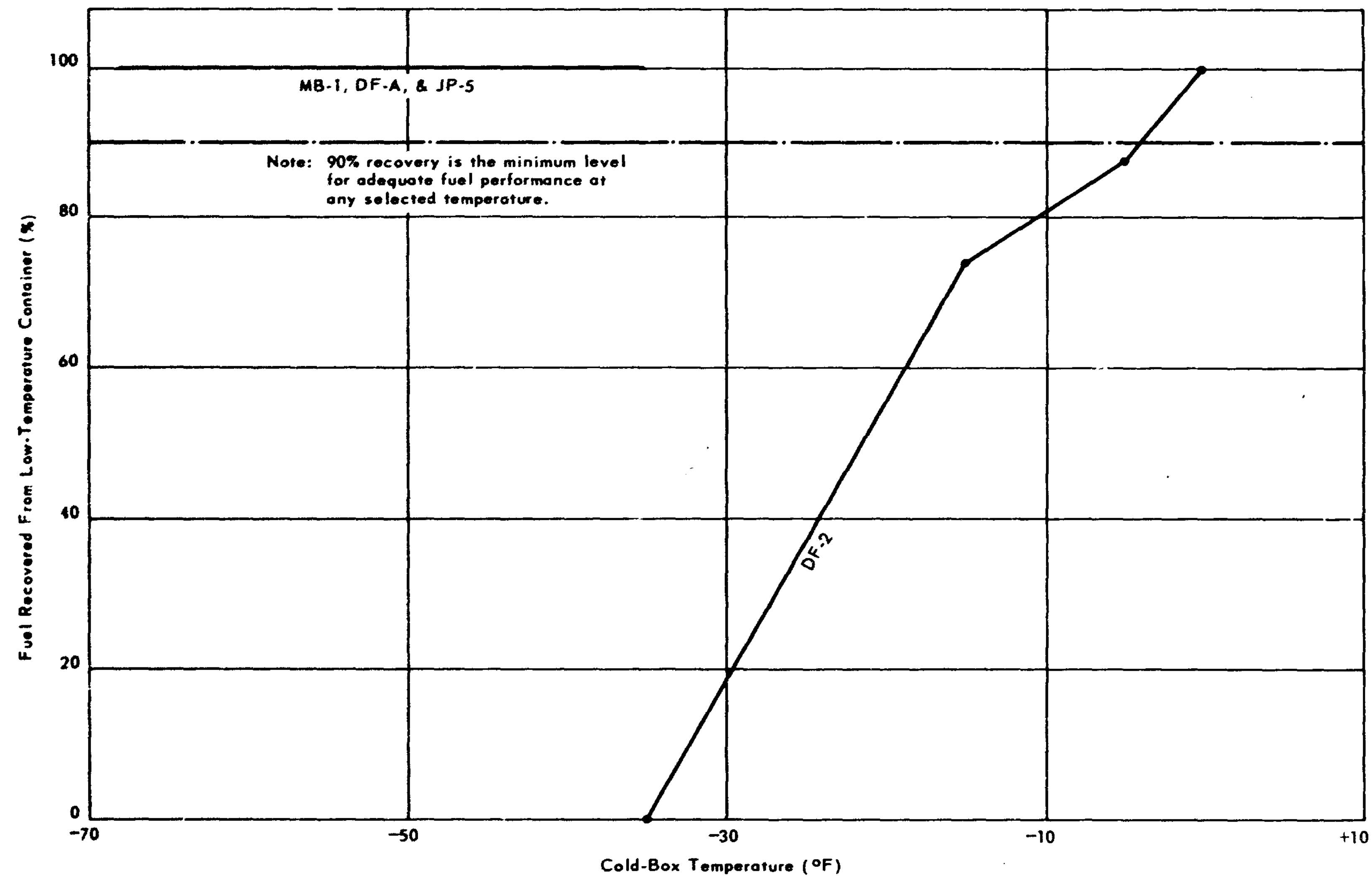

Figure 7. Cold-flow performance of four Navy fuels. (Enjay Laboratories tests.)

To summarize the Enjay final report: (1) The DF-A, JP-5, and MP-1 samples exhibited excellent cold-flow properties down to at least -68°F, (which was the lowest temperature obtainable with the test equipment available); (2) The DF-2 sample had acceptable cold-flow properties only to -4°F.

Cold-Ignition Tests. The self-ignition characteristics of a diesel fuel are obviously of very great importance; they are normally determined by the ignition delay method, which utilizes coincident flash instrumentation. The equipment, operating conditions, and procedures for this test are standardized under ASTM Designator D-613-T; the test provides a cetane rating for any given fuel sample.

Unfortunately, this method rates the fuel only under high-temperature, hot-engine conditions. Therefore, the cold-starting and warmup characteristics of a fuel must be studied separately to obtain a full picture of the fuel's low-temperature capability. The usual approach to such a study is to set up a full-scale engine in a coldroom and evaluate the actual cold-starting performance of a fuel in a series of tests at decreasing temperatures. This procedure has many disadvantages, including: (1) the expense of a large coldroom installation, (2) the consumption of large quantities of test fuel, (3) the long length of time required for any one test, and (4) the possibility of inadequate control over numerous variables.

To overcome these difficulties, the Research Center of the Pure Oil Company has developed a simplified technique for measuring the cold-starting qualities of diesel fuel (Reference 3). In this method, a single-cylinder, critical compression ratio diesel engine is motored at 600 rpm with engine coolant temperature and intake air temperature closely controlled. Important conditions maintained for this test are:

Compression ratio	14.6 to 1	Coolant temperature	68°F
Injection timing	30 degrees btdc	Inlet air temperature	37 to 39°F
Injecting quantity	3.75 cu mm/cycle	Engine speed	600 rpm

By means of an exhaust pulse recorder, the following significant characteristics are recorded:

1. Time required to accelerate the engine to 600 rpm
2. Number of compression strokes occurring before the first detectable combustion
3. Number of compression strokes occurring between random firings
4. Number of compression strokes occurring before continuous firing

Correlation of the results of this technique with the results of full-scale, multicylinder, cold-starting tests has shown that item no. 4 above gives a very accurate comparative indication of the actual cold-starting qualities of all diesel fuels in the 40-cetane number range.

In view of this correlation, arrangements were made with the Pure Oil Research Center to subject four typical fuel samples to the cold-flow ignition test.* The fuels tested were DF-2, DF-A, JP-5, and MP-1; as in the Enjay tests, the DF-A and JP-5 samples were included to provide comparative data on heavier fuels. The results of this series of tests are presented in Table 1.

Table 1. Results of Pure Oil Research Center Cold-Ignition Tests

Fuel			Average Number of Compression Strokes Before:	
Type	Sample Identification	Cetane Rating	First Fire	Continuous Firing
NCEL Fuel Samples				
MP-1	Sample 18, tank J	42.7	6.7	39.5
DF-2	Sample 2, 7/21/64	47.6	7.0	81.3
DF-A	NCEL, 2nd batch	39.9	5.8	164.8
JP-5	Sample 4, 6/22/64	41.3	6.6	182.0
Pure Oil Reference and Calibration Fuel Samples				
Com. 2	No. 1	42.7	24.2	217.1
Com. 2	No. 2	50.3	14.0	148.0

From Table 1, it can be readily seen that, on the basis of the significant characteristic, "compression strokes before continuous firing," MP-1 appears to be a very excellent cold-weather fuel and should prove much superior to any of the other test fuels in its cold-starting ability. The other fuels, ranked in order of good cold-ignition characteristics are DF-2, DF-A, and JP-5. (For complete details, see reference 4.)

*CBC purchase order no. 62583/5076-3528, of 2 Apr. 1965.

Fuel Handling and Filtration. As is the case with all low-viscosity, low-specific-gravity fuels, the successful, long-term operation of diesel engines on MP-1 fuel will depend to a major extent upon the attention and care given to fuel cleanliness. Diesel engines operating on MP-1 will not tolerate dirt or water in the fuel. Small abrasive particles, for example, which might be successfully passed through a fuel system using DF-2, may very well cause plunger scoring or injector sticking when the same system is supplied with MP-1 — primarily because of the effects of reduced viscosity.

Included under the heading of essential fuel-handling practices are:

1. Exercise of extreme care during fuel-transfer operations to avoid contamination of any type.
2. Daily draining of water accumulations from the bottoms of all fuel tanks.
3. Use and careful maintenance of an adequate system of fuel filters at the engine.

Adequate filtration at the engine requires at least a two-stage system. The first or primary filter is normally installed ahead of the fuel-transfer pump. It may be of the metal-edge type, and should remove coarse (25-micron) particles. The secondary-stage filter, placed between the transfer pump and the fuel-injection pump, must be capable of removing fine particles, 5 microns in diameter or larger. This unit is commonly a replaceable paper element. On small- and medium-sized engines it is highly advisable to include a third or final stage filter just ahead of the injection pump to remove any remaining particles, 2 microns in diameter or larger. With protection such as this, no injection equipment difficulties (sticking, scoring, or excessive wear) will be encountered when MP-1 fuel is used. It should be noted that when micronic fuel filters are used, their capacities must be very generous, because many engines recirculate a large amount of fuel in comparison to their actual fuel consumption.

It must also be kept in mind that MP-1 is a very-low-viscosity fluid (thinner than DF-A) which will cause more plunger leakage than heavier fuels. Therefore, in fuel-injection pumps having a self-contained lubrication system (such as the Bosch model PE), frequent checks should be made of the pump lubricating-oil level. If dilution becomes apparent, the oil must be immediately changed to prevent inadequate lubrication and consequent damage to the bearings of the pump. Likewise, increased injector leak-off in certain engines with inadequate drain systems, could conceivably result in crankcase dilution. With any change to the use of a less viscous fuel, good maintenance practices dictate the need for increased vigilance in the detection of incipient fuel dilution in crankcases and oil reservoirs.

Fuel-System Configuration for Low-Temperature Operation. It is widely recognized that the suitability of any given fuel for use in diesel engines under low-temperature conditions is highly influenced by the overall arrangement of the fuel system itself. In fact, the importance of good design in a diesel-fuel system for subzero temperatures can hardly be overemphasized.

All diesel fuels consist of a complex mixture of hydrocarbons, with paraffinic elements having only a limited solubility in the fuel. As previously mentioned, upon cooling these paraffinic components come out of solution as wax particles, which may (and often do) collect on fuel-filter elements and screens in sufficient quantity to restrict or block the flow of fuel. Thus, even though it may be possible to start a diesel engine, the ability to keep it running when temperatures approach that of the cloud point of the fuel depends entirely upon the components and layout of the fuel supply system.

In starting a diesel engine with the fuel at temperatures near the cloud point, two competing tendencies are immediately brought into play: (1) the steady buildup of wax on the filter elements with the attendant possibility of blockage and fuel starvation, and (2) a counterbalancing force, the gradual temperature rise of the entire fuel system as the engine warms up. This increases the temperature of the fuel, which then starts to dissolve the wax on the filter elemen.. Should the decreasing filter capacity reach the critical stage before the temperature rise becomes completely effective, the engine will lose power and possibly will stall.

For optimum performance of vehicles and equipment at low temperatures (down to temperatures at which the pour point of the fuel becomes the controlling factor), the following elementary design requirements of the fuel-supply system must be met:

1. The fuel tank must be located as close to the engine as is practical and should be protected from direct cold-air blast.

2. The fuel tank must have a convenient and readily drainable sump for the collection of moisture.

3. Fuel return lines should be located close to the fuel supply lines and should enter the same area of the fuel tank. There must be no tank outlet screen. The line from the tank to the engine must be large, as direct as possible, and contain no sharp bends or restrictions. Likewise, there must be no U-bends or low points in which water may collect and freeze.

4. Not more than one primary filter should be placed ahead of the fuel-transfer pump, and this unit must be so located as to receive adequate engine heat.

5. The secondary- and final-stage fuel filters must also be located on or near the engine in order to receive the heat required to inhibit or dispose of wax formation.

6. Radiator shutters and side panels are most effective in maintaining the temperature of fuel system components and are therefore strongly recommended, where applicable.

As may be inferred from the above recommendations, the prime requisite for obtaining satisfactory cold-weather operation from a diesel-fuel system is the effective use of engine heat to warm filters, lines, and tanks.

Space-Heater, Camp-Stove, and Lantern Tests

For the evaluation of miscellaneous heating and lighting equipment, five different types of units were purchased and tested (Reference 5). These were as follows:

1. Coleman 50,000 Btu, model 870C, space heater (Figure 8).
2. Coleman single-burner, model 502-700, Sportster stove (Figure 9).
3. Coleman two-burner model 425D camp stove (Figure 10).
4. Coleman single-mantle model 200A lantern (Figure 11).
5. Model M-1950 GI pocket stove (Figure 12).

Space-Heater Tests. Two of the model 870C units were set up in a sheltered location and each was operated at ambient temperature for a total of 300 hours; a prearranged series of heat settings ranging from "1/4-fire" to "full-fire" was used. To obtain a comparison of performance characteristics, one heater was fueled with DF-A and the other with MP-1. In addition, during the final period, the heaters were cleaned and fuels interchanged between units to bring to light any possible difference in performance caused by manufacturing variations.

During the initial portion of the test, the draft on the combustion chambers was maintained at 0.06 inch of water, as per the manufacturer's recommendations. It was soon discovered, however, that this amount of draft was insufficient and tended to promote the formation of excessive carbon and soot deposits in both units. The draft was, therefore, increased to 0.10 inch of water. At this setting both heaters operated satisfactorily.

At the conclusion of 300 hours of operating time, a detailed inspection indicated that in the model 870C space heater MP-1 is a considerably cleaner burning fuel than is DF-A. DF-A consistently caused a thicker, oilier coat of soot in combustion chambers and stacks. DF-A also formed large, clinkerlike deposits of soot between the rings in the lower combustion area, which were not in evidence when MP-1 was used as a fuel. In addition, such soot as was formed in the burning of MP-1 tended to be rather light and dry and did not adhere tightly to the metal surfaces, whereas the soot resulting from the use of DF-A was strongly attached and hard to remove.

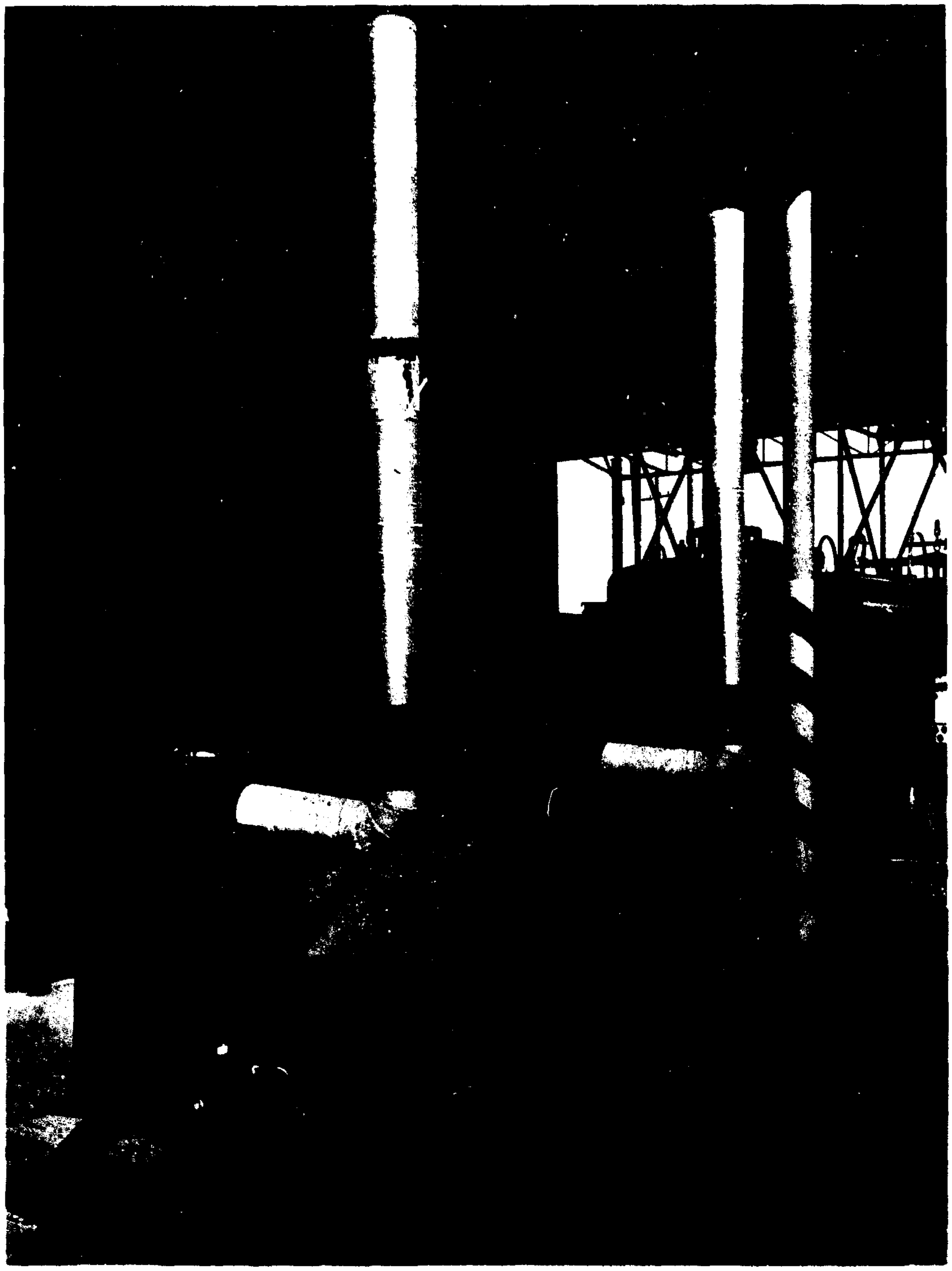

Figure 8. Coleman 50,000-Btu space heaters at test site.

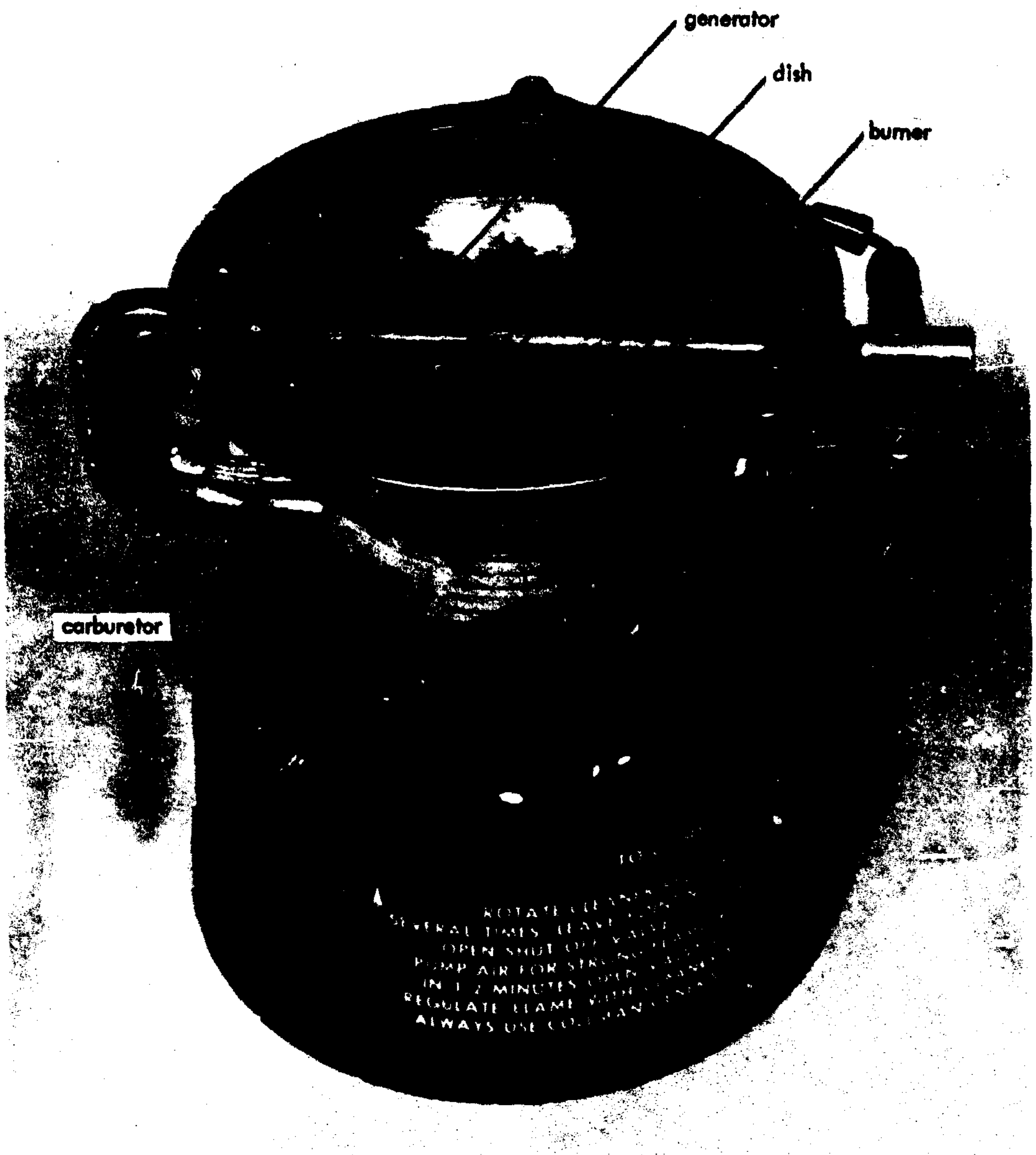

Figure 9. Coleman single-burner Sportster stove, model 502-700.

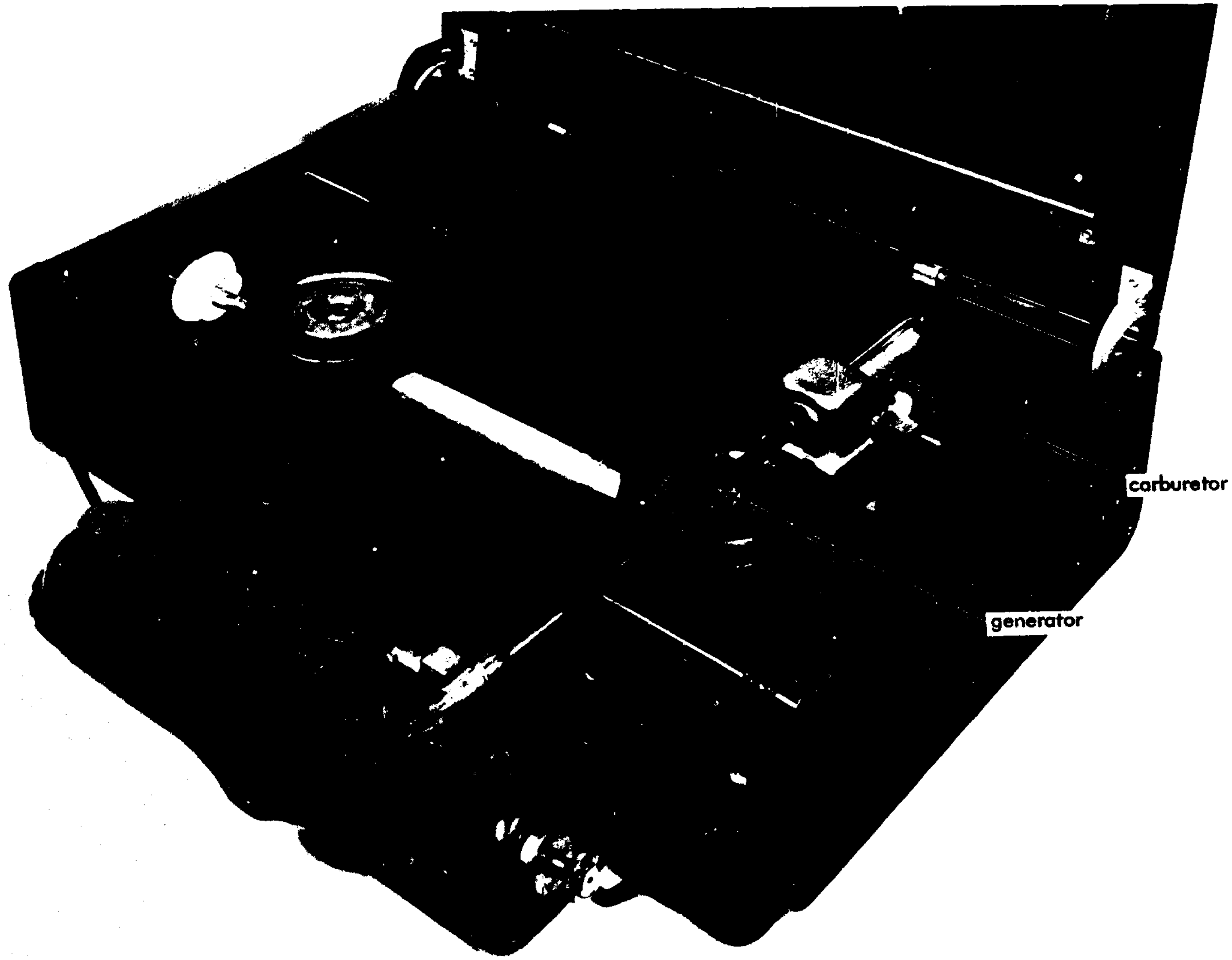

Figure 10. Coleman two-burner camp stove, model 425D.

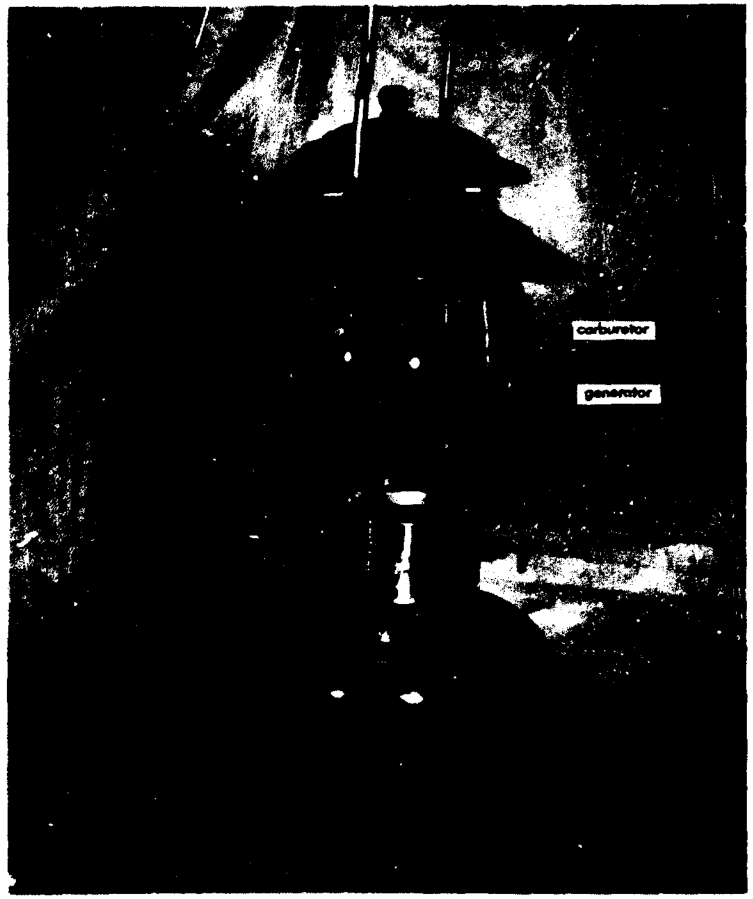

Figure 11. Coleman single-mantle lantern, model 200A.

Figure 12. GI pocket stove, model M-1950.

To establish the cold-ignition properties of these fuels when they are used in pot-type space heaters, samples of MP-1 and DF-A were placed in separate containers simulating the combustion chambers. A small wick was placed in each, and the units were then cold soaked for 24 hours at -55°F. After 24 hours' cold soaking a cigarette lighter flame ignited each wick at -55°F with no more apparent delay than at room temperature, thus indicating that low-temperature ignition should present no problems.

Camp-Stove and Lantern Tests. The single-burner Sportster stove, the two-burner camp stove, and the single-mantle lantern were all pressurized with hand pumps and were designed to operate on white (unleaded) gasoline. Two of each were received in unused condition and were given an initial short operating check on white gasoline to make certain that all were in good working order.

In the first test, which involved the two single-burner Sportster stoves, one unit was fueled with MP-1 and the other with white gasoline. When operated at 65°F ambient temperature, both stoves performed adequately, but the MP-1 unit required a few seconds longer to light than did the gasoline unit. To check for any possible differences between stoves, fuels were interchanged, but results were again the same.

Both stoves were then cold soaked at -10°F for 24 hours. Under these conditions, it was nearly impossible to light either the unit containing MP-1 or the one with white gasoline. Experimentation with various means of ignition disclosed that lighting with either fuel could be readily accomplished by placing a small piece of braided asbestos in the dished top surface of the burner, directly under the generator, and soaking this with fuel. The asbestos wick was easily fired; the generator was allowed to preheat for approximately 1 minute before an attempt was made to ignite the stove burner. With this technique, it was easy to light the stoves with either fuel at -10°F. This procedure was repeated at -20°F and was again successful. The cold chamber temperature was then lowered to -40°F. At this temperature, it was practically impossible to light either the MP-1 stove or the unit using white gasoline, regardless of the procedure used.

The second test involved the two-burner camp stoves. At 65°F, normal operation on MP-1 was possible, but ignition was slightly more difficult than with white gasoline. At -10°F, even with the use of the auxiliary asbestos wick technique, lighting with either gasoline or MP-1 was very difficult. At -20°F, it became virtually impossible to light either of the two-burner stoves. The two-burner stoves were more difficult to light at -20°F than was the single-burner Sportster model because the generator is longer and more exposed in the two-burner model.

The third test included the single-mantle lanterns. The lanterns, one fueled with MP-1 and the other with white gasoline, were taken through a series of cold-soaking and lighting attempts identical to that applied to the stoves. At 65°F, the MP-1 lantern could be lighted with no appreciable difficulty. Through the use of the auxiliary asbestos wick technique, lighting on either fuel was possible at temperatures down to and including -20°F. At -40°F, however, it was impossible to light either lantern, principally because the heavy gloves required by the operator at this temperature impaired his dexterity to the extent that he could not successfully manipulate burning matches into the small opening provided in the lantern for lighting.

To evaluate lantern performance over a period of time, both lanterns were thoroughly cleaned, refueled (one with MP-1 and the other with white gasoline), lighted, and allowed to burn for a total of 16 hours each at 65°F. At the conclusion of this test period the lanterns were completely disassembled and closely inspected. At this time it was noted that the lantern which had burned white gasoline was completely clean — inside and out (Figure 13). The unit operated on MP-1 was found to have a considerable coating of soot on the globe, the carburetor, and the ventilator. An inspection of the generator needle also revealed the presence of a hard, baked-on carbon coating, which was not in evidence in the unit operated on gasoline.

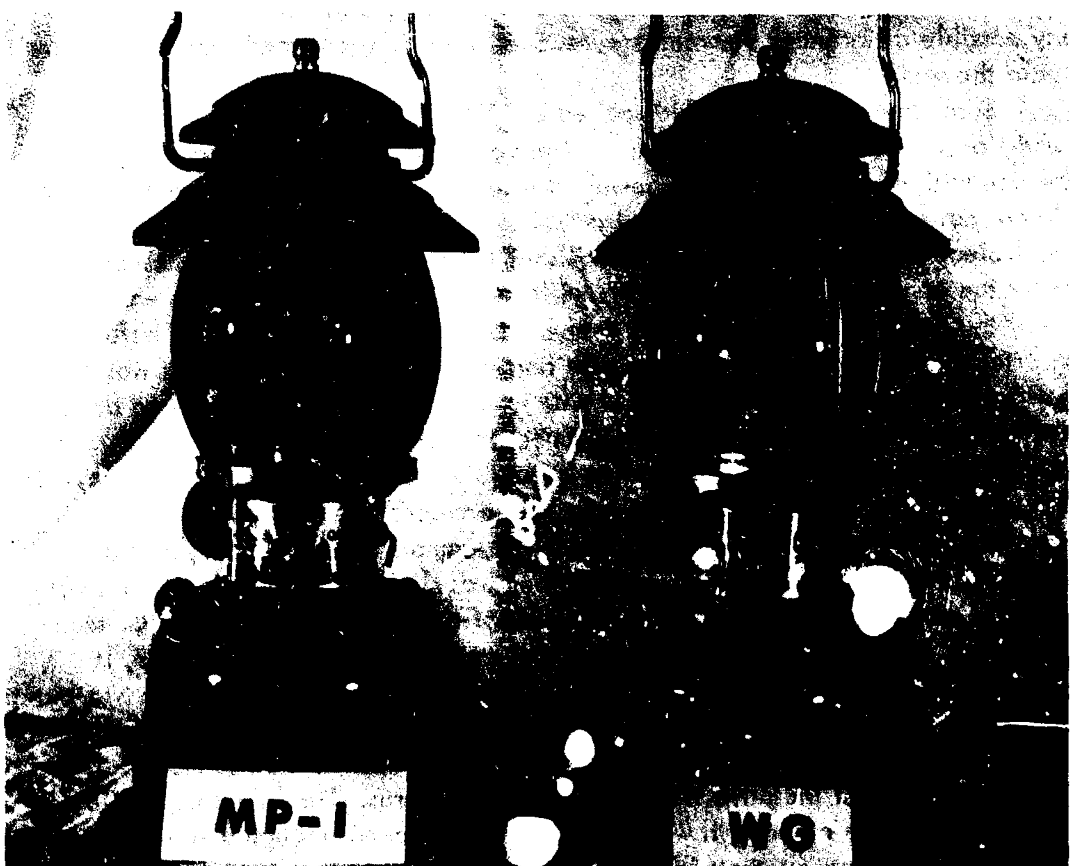

Figure 13. Single-mantle lanterns after 16-hour endurance test. (Note soot deposits on MP-1 unit.)

The fourth and final test of this series involved M-1950 GI pocket stoves (Reference 6), which were procured directly from Construction Battalion Center warehouse stocks. These are small, rugged units for use in forward areas, and are designed to burn either white or leaded gasoline. In an evaluation of cold ignition, one stove was fueled with MP-1 and the other with white gasoline. After a cold soak at -20°F, both stoves were lighted very easily through use of the manufacturer's recommended procedure. At -30°F ignition was likewise successful, with only slightly more time being required to light the MP-1 unit than was required to light the white gasoline unit. The only real difficulty encountered at these temperatures was a tendency for the pump plunger to occasionally freeze and stick.

For an endurance test of the pocket stove at ambient temperatures one stove was fueled with MP-1 and the other with regular (leaded) gasoline. Each was then lighted and allowed to burn at maximum heat setting for approximately 12 hours. Both stoves burned with a clear, blue flame throughout the entire test interval, and the performance of both was considered to be entirely normal. When the stoves were disassembled and inspected at the conclusion of the test, it was found that the generator of the MP-1 unit was slightly discolored, but the cleaning rod and fuel needle were bright and shiny. In contrast, the generator of the leaded gasoline unit was covered with thick, black deposits, as were the cleaning rod and fuel needle.

CONCLUSIONS

Following the evaluation of MP-1 fuel in diesel engines, space heaters, camp stoves, and lanterns, it was concluded that:

1. MP-1 as a fuel for medium- and high-speed diesel engines is equal to DF-A (diesel fuel, arctic) in most respects; its cold-ignition characteristics are superior to those of DF-A.

2. MP-1 is a superior fuel for use in pot-type space heaters such as the Coleman model 870C.

3. **MP-1 is not recommended as a substitute for white gasoline in commercial, portable, pressurized camp stoves and lanterns. If emergency conditions make the use of MP-1 in these units necessary, thorough and frequent cleaning of all combustion components will be necessary.**

4. **For use in the M-1950 GI pocket stove, MP-1 fuel is superior to leaded gasoline and is approximately equal to white gasoline.**

ACKNOWLEDGMENTS

The author acknowledges the assistance of Mr. John J. Bayles, Miss Judith J. Wise, Mr. Sheldon Phelps, and Mr. A. J. Coreita in conducting the endurance and cold chamber tests.

Appendix A

CHEMICAL AND PHYSICAL REQUIREMENTS OF MP-1 FUEL AND TEST METHODS

Table I of Military Specification MIL-F-23188(wep): Fuel, Multipurpose, Antarctic; MP-1 of 28 February 1962 is reproduced here to provide information on the properties of MP-1 fuel.

Property	Requirements	Fed. Test Method Std. No. 791	ASTM Method
Distillation:			
Fuel evaporated, 10% min at	175°C(347°F)		
Fuel evaporated, 50% min at	210°C(410°F)		
End point, max	260°C(500°F)	1001	D86
Residue, vol % max	1.5		
Gravity, specific 60/60°F max (API°-min)	0.816 (42.0)	401	D287
Gravity, specific 60/60°F min (API°-max)	0.763 (54.0)	401	D287
Existent gum mg/100 ml, max	7	3302	D381
Total potential residue, 16 hr aging, mg/100 ml max	14	3354	D873
Sulfur, total, % wt max	0.4	5201	D1266
Mercaptan sulfur, % wt max or	0.001	5204	D1219 or
"Doctor Sweet"		5203	D1323
Freezing point, max	-57°C(-70°F)	1411	D1477
Aniline-gravity product, min	5250	3601 & 401	D611 & D287
Aromatics, vol % max	25	3703	D1319
Aromatics, vol % min	5	3703	D1319
Olefins, vol % max	2	3703	D1319
Viscosity, centistokes at -34.4°C(-30°F) max	5	305	D445
Smoke point, min (mm)	19	2107	D1322
Water reaction, interface rating, max (sec 3.2.1)	lb	3251	
Flash point, min	43°C(110°F)	1102	D93
Ignition quality, cetane no. min	40	6051.5	D613
Thermal stability (sec 4.4.2)			
Change in press. drop in 5 hrs, in. Hg, max	13	3464	D1660
Preheater deposit, max	3		
Copper strip corrosion at 100°C(212°F)	No. 1	5325	D130

Appendix B

PETROLEUM PRODUCTS AND CHEMICALS TEST REPORT NO. 191

Report date:	29 Sept. 1964
Quality control office:	Baton Rouge, Louisiana
Manufacturer:	Humble Oil & Refining Company
Location:	Baton Rouge, Louisiana
Contract no:	P. O. 62583 4262-3514
Product:	Fuel, multipurpose, antarctic-MP-1
Specification:	MIL-F-23188(wep)
Sample no:	64/193
Date sampled:	23 Sept. 1964
Quantity (gallons):	6,425
Shipped to:	Receiving Officer, Port Hueneme, California

Tests	Specifications	Actual Results
Specific gravity, API	42.0 - 54.0	50.0
Freezing point, max (°F)	-70	below -85
Existent gum, max (mg/100 ml)	7	0.2
Potential gum, max (mg/100 ml)	14	0.4
Sulfur, total max (% wt)	0.4	0.010
Mercaptan sulfur, max (% wt)	0.003	0.003
Flash, PMC min (°F)	110	110
Aniline gravity product, min	5,250	7,146
Viscosity, max (cs at 30°F)	5	4.17
Aromatics (% vol)	5 - 25	9.6
Olefins (%)	2	0.6
Smoke point, min (mm)	19	31.0
Corrosion, ASTM max (cs)	1	passes 1A
Water reaction, max interface rating	lb	1

Tests	Specifications	Actual Results
Distillation:		
Fuel evaporated 10%, min (°F)	347	55.0
Fuel evaporated 50%, min (°F)	410	98.0
Final boiling point, max (°F)	500	383
Residue, max (% vol)	1.5	1.0
Loss, max (% vol)	1.5	1.0
Thermal stability:		
Filter ΔP, max (in. Hg)	13	0.06
Preheater deposit, max	less than 3	1
Ignition quality, min (cetane no.)	40	41.2

Appendix C

NCEL FUEL TEST AND ANALYSIS

Item	MP-1	DF-A (1964 Procurement)	DF-A (1965 Procurement)
Cetane no.	42.7	38.1	39.9
Viscosity (cs at 100°F)	1.06	1.42	1.40
Viscosity (cs at -30°F)	4.28	12.01	12.75
Sulfur (% wt)	0.02	0.10	0.11
Water and sediment (% vol)	nil	nil	nil
Distillation (°F):			
10% point	333	403	402
50% point	345	433	435
90% point	360	480	477
End point	390	524	526
Carbon residue	0.06	0.005	0.010
Ash (% wt)	0.0004	nil	nil
Flash point (°F)	115	154	152
Cloud point (°F)	no cloud at -70	no cloud	no cloud
Pour point (°F)	flows at -80	-70	-70
Freezing point (°F)	clear at -76	-74	-64
Corrosion (ASTM no.)	1A	1A	1A
Gravity, API (at 60°F)	49.9	36.9	37.0
Heating value (Btu/lb)	19,614	19,534	19,316
Aromatics (% vol)	7.75	25.28	24.80
Smoke point, min (mm)	23	16	17
Olefins (% vol)	0.37	0.57	0.60

Appendix D

CATERPILLAR MODEL D-8800 ENGINE SPECIFICATIONS
(for 500-hour endurance test)

USN No. 51-01889

Caterpillar 50-kw diesel-electric generating set
Model D-8800
Serial no. 3V321

and

USN No. 51-08890

Caterpillar 50-kw diesel-electric generating set
Model D-8800
Serial no. 3V322

Engine:

900 rpm (rated speed)
5-3/4-inch bore by 8-inch stroke
Caterpillar fuel injection system
Manufactured - 8/8/50

Generator:

220/440-volts, 3-phase, 60-cycle current
Continuous rating — 69 kva, 50 kw, 0.72 pf

Appendix E

FUEL-INJECTION PUMP CALIBRATION DATA FOR 500-HOUR TEST

Test Conditions		Generating Set No. 51-01889 (Run on DF-A During 500-Hour Test)								Generating Set No. 51-01890 (Run on MP-1 During 500-Hour Test)							
		Cubic Centimeters of MP-1 Per 500 Strokes for Cylinders:				Cubic Centimeters of DF-A Per 500 Strokes for Cylinders:				Cubic Centimeters of MP-1 Per 500 Strokes for Cylinders:				Cubic Centimeters of DF-A Per 500 Strokes for Cylinders:			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Full throttle, pump speed 450 rpm	Before 500-hour test	91	90	89	92	92	92	90	93	90	90	92	91	91	92	94	93
	After 500-hour test	90	89	88	90	92	90	90	92	88	89	90	88	91	92	93	92
High idle, pump speed 460 rpm	Before 500-hour test	23	22	20	23	24	23	21	25	21	21	23	21	22	22	25	23
	After 500-hour test	21	20	18	21	24	21	20	24	19	19	22	19	21	21	24	20

Appendix F

DIX-6-D ENGINE SPECIFICATIONS
(dynamometer test)

Manufacturer: Hercules Engine Division, Hupp Corp.

Model: DIX-6-D (diesel)

Bore and stroke: 3-5/8 by 4 inches

No. of cylinders: 6

Rating: 77 hp at 2,400 rpm (bare)

Injection equipment:

RoosaMaster injection pump

Model GF-C-L-627-11
Mfg. no. 146538-DS
Serial no. 000-56

American-Bosch injectors

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6. Military Specification MIL-S-10736E: Stove, gasoline burner, M-1950, with or without case. Dec. 28, 1962. (Supersedes MIL-S-10736D, dated Feb. 5, 1958.)

U. S. Naval Civil Engineering Laboratory
MULTIPURPOSE TYPE I (MP-1) FUEL FOR ANTARCTIC USE,
by William W. Watson
TR-446 33 p. illus May 1966 Proprietary Information

1. Antarctic fuel 2. Multipurpose type I. Y-F015-11-01-196

The specifications for a multipurpose fuel, MP-1 (MIL-F-23188) have been developed by the Bureau of Naval Weapons. This fuel, proposed for use in Antarctica in aircraft turbines, diesel engines, and space heaters, has received prior approval for use in C-130 and C-135 aircraft. The current study was undertaken to determine its suitability for use in diesel engines, space heaters, emergency camp stoves, and lanterns.

These tests have indicated that MP-1 is a satisfactory substitute for DF-A (diesel fuel, Arctic) in medium and high speed diesel engines, and in pot-type space heaters. MP-1 is not recommended as a regular fuel for pressurized, commercial camp stoves and lanterns which normally burn white gasoline, although under urgent conditions, it may be used in these units for short periods of time.

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Space heaters						
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